Addressing uncertainty in efficient mitigation of agricultural greenhouse gas emissions

Citation for published version:
Eory, V, Topp, CFE, Butler, A & Moran, D 2018, 'Addressing uncertainty in efficient mitigation of agricultural greenhouse gas emissions', *Journal of agricultural economics*, vol. 69, no. 3, pp. 627-645. https://doi.org/10.1111/1477-9552.12269

Digital Object Identifier (DOI):
10.1111/1477-9552.12269

Published In:
Journal of agricultural economics

Addressing uncertainty in efficient mitigation of agricultural greenhouse gas emissions

Vera Eory, Cairistiona F. E. Topp, Adam Butler and Dominic Moran

Online Supplementary Material

Introduction

This study is based on a bottom-up ("engineering") marginal abatement cost curve (MACC) developed for the UK agriculture (MacLeod et al., 2010; Moran et al., 2008; Moran et al., 2011). The first two sections of the supplementary material briefly outline the methodology and the mitigation options. The third section provides the modes of the input values, while the last section presents additional results.

Marginal abatement cost curve calculations

The annual national abatement potential and the cost-effectiveness of each measure is derived from data on i) land area (activity), ii) estimated applicability, additional uptake and area-based annual abatement rate, and iv) area-based net costs. This information is summarised in Figure 1.

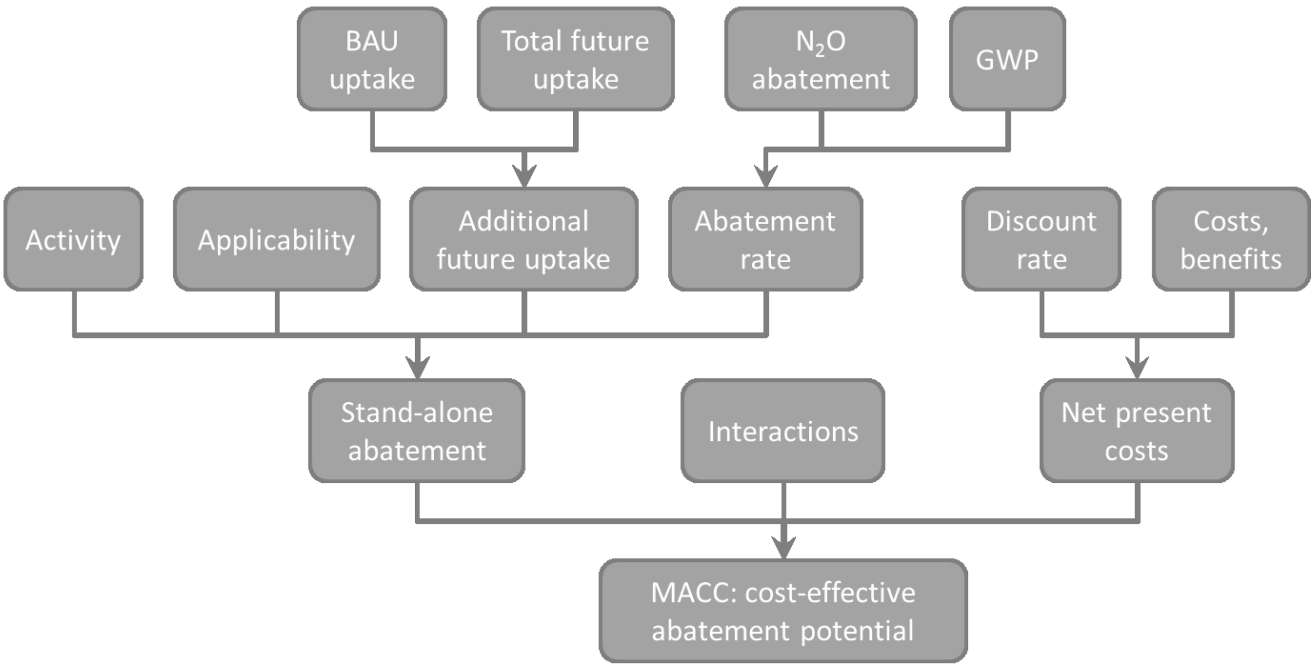

Figure 1 Schematic structure of the MACC calculations

Stand-alone abatement

The stand-alone abatement for mitigation option *i* and year *t* was calculated as follows:

$$Stand\ alone\ abatement_{i,t,u} = \left(\sum_{j=1}^{4} Activity_j * Applicability_{i,j}\right) * \ Additional\ future\ uptake_{t,u} * Abatement\ rate_{i,t}$$

$Activity_j$ is the area of land category j. The land area was divided into four categories: grassland including less favoured areas (but not including rough grazing), cereals and oil seeds, root crops (potatoes, sugar beet, turnips, swedes, fodder beet and mangolds), other crops (hops, horticulture, beans, peas, linseed, flax, fallow). Future land use projections were sourced from Shepherd et al. (2007).

$Applicability_{i,j}$ is the proportion of land area category *j* where mitigation option *i* is agronomically feasible . This was derived from expert opinion.

$Additional\ future\ uptake_t$ is defined as the proportion of applicable land where the mitigation options are likely to be applied as a result of mitigation policy (i.e. additional to baseline uptake) in year *t*, under uptake scenario *u*. Four uptake scenarios were defined, low feasible potential (LFP), central feasible potential (CFP), high feasible potential (HFP) and maximum technical potential (MTP).These were based on the estimated net costs of the measures and ease of measure enforcement. Estimates for maximum additional uptake by 2022 were derived from *ex-post* studies of agri-environmental compliance/uptake. For other years the uptake was calculated as a linear interpolation of the uptake in 2022 and zero uptake in 2008.

$Abatement\ rate_{i,t}$ is the annual average abatement rate of mitigation option i for year t on land area where the mitigation option is implemented. This was derived from expert opinion.

Interactions

Mitigation interactions between the measures were considered via interaction factors, reflecting how total mitigation achieved by implementing two options at the same time on the same field/farm differs from the sum of the mitigation achievable by the separate implementation of the two options. Note that we do note consider the addition possibility of interaction between financial costs and benefits.

During the ordering of the options the interaction factors were used to adjust the abatement potential of the mitigation options. After the selection of the first option the abatement potentials of all the other options were multiplied by the respective interaction factors, and the process repeated after each ranking step. If two options have no GHG synergies or trade-offs then $IF = 1$. If the subsequent option is not applicable after the implementation of the first, or its abatement is reduced to 0, then $IF = 0$. The adjustment of the mitigation potential was only applied to the proportion of land area where the two options were estimated to be implemented together (assuming a random probability of implementation).

The interaction factors were derived from expert opinion.

Financial costs and benefits

Financial costs and benefits of the mitigation options were modelled in the whole far linear programming model SAC Farm Level Model (Renwick, 2005). The baseline farm data were derived from Farm Business Survey[1] (baseline year 2006), while the effects of the options on the resource use and outputs were derived from expert opinion.

Short description of the mitigation options

- Using biological fixation to provide N inputs (BiolFix): Using legumes to biologically fix nitrogen (N) and respectively reducing N application rates to reduce N_2O emissions.
- Reducing nitrogen fertiliser (NRed): reducing N application rate (reduce N_2O emissions) below the economic optimum, resulting in yield reduction.
- Improving land drainage (Drain): improving deteriorated drainage systems to reduce wet conditions and thus reduce N_2O emissions.
- Avoiding nitrogen application in excess (NExcessRed): reducing N application (reduce N_2O emissions) to eliminate excess N use (N applied over optimum recommended rates).
- Using manure nitrogen to its full extent (NOrgFull): using the organic N content of manures optimally while reducing mineral N application accordingly to reduce N_2O emissions.
- Introducing new species (including legumes) (NewSpec): cultivating not commonly planted crop varieties in the UK which use N more efficiently to achieve N_2O reductions.
- Improving the timing of mineral nitrogen application (MinNTime): matching mineral N application time with the time crops need the N most to reduce N_2O emissions.
- Using controlled release fertilisers (CRF): using a form of mineral N fertiliser that releases the N at a slower rate than conventional fertilisers, thus reducing N_2O emissions.
- Using nitrification inhibitors (NI): using nitrification inhibitors to reduce nitrification rates, providing a longer N source for the crops and reducing N_2O emissions.

[1] http://www.farmbusinesssurvey.co.uk/

- Improving the timing of slurry and poultry manure application (OrgNTime): matching organic N application time better with the crops need for N most to reduce N_2O emissions.
- Adopting systems that are less reliant on inputs (LowInput): moving production systems using less input (for the same output) to reduce overall GHG emissions.
- Adopting plant varieties with improved N-use efficiency (HighNUE): selective breeding of crops for varieties with lower N input requirements (for the same output) to reduce N_2O emissions.
- Separating slurry applications from fertiliser applications by several days (SepSlFert): leaving an interval of several days between mineral N application and slurry spreading to avoid wet conditions for mineral N application which would result in high N_2O emissions.
- Using reduced tillage and no-tillage techniques (LowTill): using cultivation techniques that reduce soil disturbance keeping more carbon in the soil.
- Use composts and straw-based manures in preference to slurry (Compost): using composts to provide steadier release of organic N and reduce N_2O emissions.

Mode of the input values

The mode of the input values are presented in Table 1 – Table 8.

Table 1 Activity values (ha)

Year	Land category 1	Land category 2	Land category 3	Land category 4
2012	1,227,157	484,788	52,523	13,639
2017	1,246,258	500,815	52,048	13,890
2022	1,242,535	494,633	50,882	13,792

Table 2 Applicability values

Mitigation option	Land category 1	Land category 2	Land category 3	Land category 4
BiolFix	0.58	0.2	0.2	0.2
NRed	0.58	0.91	0.9	0.9
Drain	0.4	0.3	0.3	0.3
NExcessRed	0.2	0.2	0.2	0.2
NOrgFull	0.25	0.15	0.15	0.15
NewSp	0.6	0.4	0.3	0.3
MinNTime	0.36	0.4	0.4	0.4
CRF	0.72	0.91	0.8	0.8
NI	0.72	0.91	0.91	0.91
OrgNTime	0.34	0.15	0.15	0.15
LowInput	0.6	0.4	0.3	0.3
HighNUE	0.2	0.6	0.4	0.4
SepSlFert	0.34	0.22	0.22	0.22
RedTill	0	0.5	0.1	0.1
Compost	0.17	0.11	0.11	0.11

Table 3 Maximum additional uptake values in 2022

Net costs	Ease of enforcement	LFP	CFP	HFP	MTP
<=0	Easy	0.18	0.45	0.92	1
>0	Easy	0.07	0.45	0.92	1
<=0	Difficult	0.18	0.45	0.85	1
>0	Difficult	0.07	0.45	0.85	1

Table 4 GHG abatement rate values (kg N_2O ha^{-1} $year^{-1}$)

Mitigation option	Year	Value	Ease of enforcement	Non-zero probabilities for negative values
BiolFix	2012-2022	2.517	Easy	No
NRed	2012-2022	1.678	Difficult	No
Drain	2012-2022	2.013	Easy	Yes
NExcessRed	2012-2022	0.336	Difficult	No
NOrgFull	2012-2022	1.510	Difficult	No
NewSp	2012-2022	1.678	Easy	Yes
MinNTime	2012-2022	0.336	Difficult	Yes
CRF	2012-2022	1.007	Difficult	No
NI	2012-2022	0.403	Difficult	No
OrgNTime	2012-2022	1.007	Difficult	Yes
LowInput	2012-2022	0.671	Easy	No
HighNUE	2012-2017	0.000	Easy	Yes
HighNUE	2022	0.336		
SepSlFert	2012-2022	0.336	Difficult	Yes
RedTill	2012-2022	0.503	Easy	Yes
Compost	2012-2022	0.671	Easy	Yes

Table 5 GWP of N_2O (kg N_2O kg CO_2 $^{-1}$)

N_2O	298

Table 6 Interaction factors

Latter to the right Former below	BiolFix	NRed	Drain	NExcessRed	NOrgFull	NewSp	MinNTime	CRF	NI	OrgNTime	LowInput	HighNUE	SepSIFert	RedTill	Compost
BiolFix	1	0.55	0.7	0.55	0.9	0.5	0.55	0.55	0.625	0.9	0.65	1	0.55	1	1
NRed	0.55	1	0.7	0.55	0.9	0.5	0.9	0.75	0.75	0.9	0.65	1	0.9	0.9	1
Drain	0.7	0.7	1	0.9	0.9	1.05	1	1	1.05	1.05	1	1	1	1.1	1
NExcessRed	0.55	0.55	0.9	1	0.8	0.5	0.6	0.75	0.75	0.5	0.65	0.9	0.9	0.9	0.9
NOrgFull	0.9	0.9	0.8	0.9	1	0.75	1	0.6	1	0.2	0.55	1	0.6	0.75	1
NewSp	0.5	0.5	1.05	0.5	0.75	1	0.9	0.9	0.9	0.9	0.75	0.85	1	1	1
MinNTime	0.55	0.9	1	0.9	0.6	0.9	1	0.95	1	1	0.9	1	0.6	1.05	1
CRF	0.55	0.75	1	0.75	0.6	0.9	0.95	1	0.75	0.9	0.75	0.9	0.75	0.9	0.9
NI	0.625	0.75	1.05	0.75	1	0.9	1	0.75	1	0.9	0.75	1	1	0.9	0.9
OrgNTime	0.9	0.9	1.05	0.9	0.55	0.9	1	0.9	0.9	1	0.75	1	0.6	0.5	0.75
LowInput	0.65	0.65	1	0.65	0.55	0.75	0.9	0.75	0.75	0.75	1	1	0.75	0.5	0.75
HighNUE	1	1	1	1	1	0.85	1	0.9	1	1	1	1	0.9	0.9	0.9

Latter to the right / Former below	BiolFix	NRed	Drain	NExcessRed	NOrgFull	NewSp	MinNTime	CRF	NI	OrgNTime	LowInput	HighNUE	SepSIFert	RedTill	Compost
SepSlFert	0.55	0.9	1	1	1	1	1	0.75	1	1	0.75	1	1	1.05	0.75
RedTill	1	0.9	1.1	1	0.75	1	1.05	0.9	0.9	0.5	0.5	1	1.05	1	0.5
Compost	1	0.9	1	1	1	1	1	0.9	0.9	0.9	0.75	1	0.75	0.5	1

Table 7 Net present cost values (£$_{2008}$ ha^{-1} year^{-1})

Mitigation option	2012	2017	2022
BiolFix	16.42	40.71	43.27
NRed	42.43	54.97	61.52
Drain	16.94	9.82	0.38
NExcessRed	-4.85	-6.98	-9.13
NOrgFull	8.01	5.18	1.40
NewSp	18.54	24.51	24.69
MinNTime	-30.06	-29.14	-33.14
CRF	25.00	30.12	47.56
NI	23.30	33.02	49.79
OrgNTime	-15.56	-23.49	-17.38
LowInput	18.38	18.80	17.26
HighNUE	-3.94	-11.05	-20.50
SepSlFert	0.00	0.00	0.00
RedTill	111.00	28.00	-24.00
Compost	0.00	0.00	0.00

Table 8 Discount rate

Discount rate	0.07

Further results

Table 9 presents the CV of the cost-effective abatement potential across all combinations of year, adoption scenario, level of uncertainty and PDF shape. The narrow PDFs resulted in CVs between 9.6% and 51.4% across the scenarios; the CV increased to between 40.0% and 107.3% for the wide PDFs. The assumption on the width of the PDF had the highest impact on the uncertainty, with the average CV for narrow PDFs being only 17.5% while the average CV for the wide PDFs was 60.0%.

Table 9 Lowest and highest CV of the cost-effective GHG abatement for different simulations and average CV of relevant simulations

Uncertainty source	PDF shape	Level of uncertainty	Year	Adoption scenario	CV (%)		
					Lowest	Highest	Average
All sources combined	All three scenarios	All three scenarios	All three years	All four scenarios	9.6	107.3	38.3
GWP	All three scenarios	All three scenarios	All three years	All four scenarios	3.9	17.1	9.8

Uncertainty source	PDF shape	Level of uncertainty	Year	Adoption scenario	CV (%)		
					Lowest	Highest	Average
Activity level	All three scenarios	All three scenarios	All three years	All four scenarios	2.9	11.6	6.9
Applicability	All three scenarios	All three scenarios	All three years	All four scenarios	3.4	21.7	11.4
Adoption	All three scenarios	All three scenarios	All three years	All four scenarios	1.0	67.1	19.6
Interaction factors	All three scenarios	All three scenarios	All three years	All four scenarios	2.4	23.4	11.3
Abatement rate	All three scenarios	All three scenarios	All three years	All four scenarios	6.7	33.2	18.0
Net costs	All three scenarios	All three scenarios	All three years	All four scenarios	0.7	10.0	4.8
All sources combined	Censored normal	All three scenarios	All three years	All four scenarios	11.9	107.3	45.6
All sources combined	Truncated normal	All three scenarios	All three years	All four scenarios	12.2	69.9	38.4
All sources combined	Triangular	All three scenarios	All three years	Any	9.6	57.5	31.1
All sources combined	All three scenarios	Narrow PDFs	All three years	All four scenarios	9.6	51.4	17.5
All sources combined	All three scenarios	Medium PDFs	All three years	All four scenarios	22.1	76.9	37.5
All sources combined	All three scenarios	Wide PDFs	All three years	All four scenarios	40.0	107.3	60.0
All sources combined	All three scenarios	All three scenarios	2012	All four scenarios	12.6	107.3	38.1
All sources combined	All three scenarios	All three scenarios	2017	All four scenarios	10.9	87.1	33.5
All sources combined	All three scenarios	All three scenarios	2022	All four scenarios	9.6	81.1	32.7
All sources combined	All three scenarios	All three scenarios	All three years	LFP	16.8	107.3	49.0
All sources combined	All three scenarios	All three scenarios	All three years	CFP	10.6	94.1	38.1
All sources combined	All three scenarios	All three scenarios	All three years	HFP	10.0	75.0	33.5
All sources combined	All three scenarios	All three scenarios	All three years	MTP	9.6	78.7	32.7

The censored normal distribution produced higher CV than the other two distributions because it was the only model to allow a non-zero probability where the true value will be equal to the boundary of the parameter space of the input variable (e.g. 0 or 1, for adoption). The uncertainty with the truncated normal distributions was similar to those with triangular distributions, but uncertainty was generally lowest for the latter.

The CV decreased with increasing adoption rate (from LFP to MTP), and also as the results were projected further into the future. The increasing adoption rate reduced the relative uncertainty of the adoption rate, as uncertainty was expressed as an absolute value. This reduction in the adoption rate's relative uncertainty reduced the uncertainty of the higher adoption rate scenarios (MTP, HFP), and also 2022 and 2017 results, due to the assumption of increasing adoption rate over time in the MACC calculations.

The contribution of the uncertainty of each input group to the uncertainty of the cost-effective abatement was examined by propagating the uncertainty of one source at a time for all the three years, four adoption scenarios, three levels of uncertainty and three PDF distribution types. On average the uncertainties in the adoption and abatement rates were the most important contributors (average CV 19.6% and 18.0%, respectively). In simulations with a low level of adoption (year 2012 or adoption scenario LFP), the uncertainty associated with the adoption of mitigation options was more significant, whereas in simulations with a high level of adoption the uncertainty in the abatement rate caused higher uncertainty in the output. The uncertainties in the net cost and activity level were usually the least important in the output uncertainty (average CV 4.8% and 6.9%, respectively). The assumptions on the uncertainties of the input groups meant that the highest uncertainty ranges were assigned to net costs and abatement and the lowest to activity levels and GWP. The results suggest that the uncertainty in the GWP and the adoption rate gained importance when the uncertainty of the cost-effective GHG abatement is considered, while the uncertainty of the net costs became less important (Table 10 Comparison of the relative assumed level of the input group uncertainty to the relative contribution to output uncertainty of the input group uncertainty).

Table 10 Comparison of the relative assumed level of the input group uncertainty to the relative contribution to output uncertainty of the input group uncertainty

	Assumption on the relative level of uncertainty in the input group	**Relative contribution of input uncertainty to the uncertainty of the cost-effective abatement**
Lowest	Activity level, GWP	Activity level, net costs
Medium	Applicability rate, adoption rate, IF	Applicability rate, IF, GWP
Highest	Net costs, abatement rate	Adoption rate, abatement rate

References

MacLeod, M., Moran, D., McVittie, A., Rees, R., Jones, G., Harris, D., Antony, S., Wall, E., Eory, V., Barnes, A., Topp, Cairistiona F. E., Ball, Bruce, Hoad, Steve, and Eory, L. *Review and Update of UK Marginal Abatement Cost Curves for Agriculture* (London: Committee on Climate Change, 2010).

Moran, D., MacLeod, M., Wall, E., Eory, V., McVittie, A., Barnes, A., Rees, R., Topp, C.F.E. and Moxey, A. 'Marginal abatement cost curves for UK agricultural greenhouse gas emissions', *Journal of Agricultural Economics*, Vol. 62, (2011) pp. 93--118.

Moran, D., MacLeod, M., Wall, E., Eory, V., Pajot, G., Matthews, R., McVittie, A., Barnes, A., Rees, R., Moxey, A., Williams, A. and Smith, P. *UK Marginal Abatement Cost Curves for the Agriculture and Land Use, Land-Use Change and Forestry Sectors out yo 2022, With Qualitative Analysis of Options to 2050*, Report No. RMP4950 (London: Committee on Climate Change, 2008).

Renwick, A. *Farm Level Economic Impacts of Energy Crop Production*, Report No. NF0431 (London: Defra, 2005).

Shepherd, M. A., Anthony, S., Temple, M., Burgess, D., Patton, M., Renwick, A., Barnes, A. and Chadwick, D. *Baseline Projections for Agriculture and Implications for Emissions to Air and Water*, Report No. SFF0601 (London: Defra, 2007).